Variation in Numbers of Bacteria on Paired Chicken Carcass Halves

J. A. Cason[1] and M. E. Berrang

USDA, Agricultural Research Service, Russell Research Center, Poultry Processing
and Meat Quality Research Unit, P.O. Box 5677, Athens, Georgia 30604-5677

ABSTRACT Bacterial counts from paired broiler carcass halves were examined for relationships between numbers and kinds of bacteria that might indicate fecal contamination. Broiler carcasses removed from a commercial processing plant just before chilling were split aseptically along the midline, and each side was rinsed in 400 mL of phosphate buffered saline for 1 min with either mechanical or hand shaking. Both halves of six carcasses were rinsed on four different days for a total of 24 carcasses sampled with each shaking method. Aerobic bacteria, coliforms, *Escherichia coli*, and *Campylobacter jejuni* were enumerated and summed to obtain whole carcass counts. There were no significant ($P < 0.05$) differences in numbers of bacteria recovered by the two rinse methods. In left-right comparisons, only *E. coli* was significantly different ($P = 0.04$), with the right side having higher counts (least-square means of 1.09 vs. 0.97). For aerobic plate count (APC), coliforms, *E. coli*, and *Campylobacter*, correlations between paired left and right side counts were between 0.78 and 0.86. The correlation between whole carcass counts and absolute left-right differences was significant for APC (0.43), but was not significant for coliforms, *E. coli*, and *Campylobacter*, so higher whole carcass counts were not associated with higher counts on one side of the carcass. Correlations between different bacteria on whole carcasses were significant for *E. coli*-APC (0.39), *E. coli*-coliforms (0.67), and APC-coliforms (0.71), but other combinations had non-significant correlations. The correlation was not significant between *E. coli* and *Campylobacter*, a relatively fragile organism whose presence can be interpreted to indicate fairly recent fecal contamination. There were no indications that high *E. coli* counts on inspection-passed, prechill carcasses indicated recent fecal contamination.

(*Key words*: Aerobic plate count, *Campylobacter*, *Escherichia coli*, carcass rinses, carcass halves)

INTRODUCTION

The use of paired carcass halves in testing of treatments to reduce salmonellae on processed poultry was suggested by Izat et al. (1990). In that study there was less variation in most-probable-number (MPN) estimates of salmonellae on left and right halves of the same prechill carcass compared to MPN of salmonellae on different carcasses. The authors suggested that testing the effects of various chemical or physical treatments on salmonellae could be done with greater sensitivity by using left and right carcass halves as a block within experimental designs.

Other researchers have also sampled bacteria on left and right halves of carcasses. Kotula (1966) reported that swab sampling of prechill and chilled chicken carcasses recovered similar numbers of aerobic bacteria on corresponding areas on the opposite halves of the carcass. Kinsley and Mountney (1966) swabbed opposite halves of carcasses and reported no difference in counts of spoilage bacteria on left and right sides of carcasses. Thomas and McMeekin (1980) took skin samples from opposite sides of the breast of immersion-chilled broiler carcasses and subjected them to either stomaching or blending. They found no significant differences in numbers of aerobic bacteria from skin on opposite sides of carcasses, although no skin samples from opposite halves were treated in exactly the same way. Left and right halves from the same carcass were used by Jetton et al. (1992) to test different rinse media for efficacy in recovering bacteria from chilled carcasses. There were no significant differences in recovery of aerobic bacteria, total coliforms, or *E. coli* when carcass halves were rinsed with either saline or distilled water, but no paired halves were rinsed in the same diluent.

Whatever left-right variation there might be in counts of bacteria occurs within any variation between carcasses, sampling days, and many other factors. McNab et al. (1993) and Renwick et al. (1993) found that carcass-to-carcass variation (rather than variation from such sources

Abbreviation Key: APC = aerobic plate count; MPN = most probable number.

as farm, lot, and processing plant) accounted for most of the variability in MPN estimates of aerobic bacteria on prechill carcasses. Incidence of pathogens such as salmonellae is usually thought of as flock related, although the percentage of positive carcasses in a flock may vary widely. Incidence of *Campylobacter* is often thought of as an all-or-none situation, with high percentages of *Campylobacter*-positive carcasses within positive flocks (Jacobs-Reitsma et al., 1995).

Relationships between different bacteria on carcasses, especially between pathogens and nonpathogens, are of great interest (Cason et al., 1997). Traditional cultural techniques for detecting bacterial pathogens are time consuming, so microbiologists have looked for index organisms that might signal the presence of pathogens and allow greater control over bacterial contamination during poultry processing. Relationships between bacteria may not be entirely stable on carcasses, however. Bacteria attach to carcass surfaces relatively quickly and are then difficult to remove (Notermans et al., 1980), but reprocessing studies have clearly demonstrated reductions in numbers of some carcass bacteria in rinse samples when fecally contaminated carcasses are washed soon after contamination occurs (Blankenship et al., 1975; Blankenship et al., 1993; Waldroup et al., 1993; Powell et al., 1995; Fletcher et al., 1997). Carcass washing in poultry plants today is more vigorous and uses far more water than was common only a few years ago. Any predictive relationships between bacteria removed from carcasses by rinsing might be affected by vigorous carcass washing.

Dickens et al. (1985) performed carcass rinses by both machine and hand shaking. Means of bacterial counts were not different by the hand-shaking method, but less variation was reported in machine-shaken rinses. Previous studies with half carcasses have used hand shaking (Izat et al., 1990; Jetton et al., 1992), swabbing (Kotula, 1966; Kinsley and Mountney, 1966) or skin sampling (Thomas and McMeekin, 1980).

The purposes of the present experiment were 1) to test the observation of Izat et al. (1990) concerning numbers of salmonellae on opposite halves of the same carcass for other bacteria, especially *E. coli* and *Campylobacter* that are commonly found in feces, 2) examine statistical interrelationships between numbers of different bacteria on poultry carcasses during slaughter, and 3) to compare mechanical shaking with hand shaking of half carcasses.

MATERIALS AND METHODS

Sampling

Two trials were conducted with broiler carcasses taken from a processing plant on 4 d in each trial. The plant processed 6-wk-old chickens under typical industry conditions that included a 2-min scald in water at approximately 57 C. On each sampling day, six carcasses were

aseptically removed from the processing line between the final carcass washer and the chiller. Carcasses were taken before chilling to avoid the likelihood that immersion in water might change the variation in numbers of bacteria on different halves of carcasses. Gloves were changed between carcasses, which were handled as little as possible. Carcasses were sealed in individual bags, covered with ice, and returned to the laboratory where all carcasses were placed in a 4 C refrigerator.

At the laboratory, carcasses were removed individually from the refrigerator and placed supine on a cutting board covered first with aluminum foil and then with a sterile lab towel. Carcasses were cut into left and right halves using a sanitized, serrated knife to cut along the midline, with the keel and the backbone as guides. The orientations of the knife and the cutting board were kept constant relative to the carcass, in order to avoid moving bacteria between the two halves. Latex gloves, foil, paper towel, and knife were changed for each carcass. Left and right halves were put into individual, labeled plastic bags and returned to the refrigerator.

Trial 1

In the same order that they had been placed in the refrigerator, bagged carcass halves were removed and placed with the skin side down in an orbiting shaker.[2] The plastic bag was held upright by a metal enclosure attached to the shaker table. When the machine was turned on and rpm reached 250, 400 mL of sterile water were added to the bag. The carcass half was not turned over during shaking, but rinse liquid splashed over the upper portion (the interior of the carcass) during shaking. After 1 min, the shaker was turned off and the carcass half was removed from the bag with a clean glove. Recovered rinse liquid was returned to the refrigerator, and the carcass half was discarded.

Trial 2

Trial 2 was identical to Trial 1 except that halves were shaken by hand instead of mechanically. Each carcass half was held in an upper corner of a plastic bag while 400 mL of sterile water was added to the lower part of the bag. The carcass half was allowed to slide down into the rinse liquid, and then shaking was started. The half was shaken skin down with a complete, one-dimensional, horizontal oscillation of 10 cm every 0.5 s for 1 min. The half was not turned over during shaking, but rinse liquid splashed over the upper portion. When rinsing was completed, the carcass half was quickly removed from the bag and discarded. Rinse liquid was returned to the refrigerator.

Microbiological Analysis

Aliquots were removed from each rinse for aerobic plate count (APC), coliform, *E. coli*, and *Campylobacter* analysis. Samples from three carcasses were discarded

because sharp bones in the carcass halves punctured the bags and caused leaks during shaking.

Total aerobic bacterial populations were enumerated on plate count agar.[3] One-tenth milliliter from a serial dilution of samples was plated in duplicate on the surface of the agar, spread, and incubated at 35 C for 18 to 24 h prior to counting the resulting colony forming units. Coliform and *E. coli* counts were made by plating 1 mL from a serial dilution of the samples on duplicate *E. coli* Petrifilm™. Plates were then incubated at 35 C for 18 to 24 h, and colony types characteristic of coliform and *E. coli* were counted. Following serial dilutions in phosphate-buffered saline, *Campylobacter* was enumerated by inoculating duplicate Campy-Cefex agar plates (Stern et al., 1992). One-tenth milliliter was spread on the surface of each plate, and plates were incubated at 42 C for 36 h in a microaerophilic environment (5% O_2, 10% CO_2, 85% N). Colony-forming units characteristic of *Campylobacter* were counted. Each colony type counted as *Campylobacter* from each sample was confirmed as a member of the genus by examination of cellular morphology and motility on a wet mount under phase contrast microscopy. Each colony type was further characterized by a positive reaction on a latex agglutination test kit.[4]

Statistical Analysis

Counts for paired carcass halves were added to get numbers of bacteria on whole carcasses. All bacterial counts were converted to $\log_{10}(cfu/mL)$ for statistical analysis. Analysis of variance was conducted using PROC GLM (SAS Institute, 1987) to test for differences in rinsing methods and for systematic left-right differences in bacteria recovered from the carcass halves. A completely randomized design was used to test for differences between shaking methods. Mean counts for left and right halves of carcasses were tested in a random block design analysis of variance using the day-by-half interaction as the error term. Correlations between numbers of bacteria on half and whole carcasses were determined using PROC CORR.

RESULTS AND DISCUSSION

Machine Shaking vs. Hand Shaking

Means for APC, coliforms, *E. coli*, and *Campylobacter* recovered from rinses of left and right halves of carcasses by the two rinsing methods are shown in Table 1. Analysis of variance indicated no significant differences in counts due to rinsing method (machine shaking versus hand shaking). Dickens et al. (1985) found that mean counts of bacteria were either not significantly different or only slightly different in the case of Enterobacteriaceae (0.26 logs) when carcasses were rinsed by hand or by machine,

[3]Becton-Dickson, Sparks, MD 21152.
[4]Integrated Diagnostics, Baltimore, MD 21227.

TABLE 1. Mean log10 (cfu/mL) and standard deviation of counts of aerobic plate count (APC), coliforms, *Escherichia coli*, and *Campylobacter* recovered from rinses of half carcasses when sampled by rinsing using mechanical shaking (Trial 1) or hand shaking (Trial 2)

		Left half		Right half	
	n	Mean	SD	Mean	SD
Mechanical shaking					
APC	23	2.6	0.5	2.7	0.5
Coliforms	23	1.6	0.6	1.6	0.6
E. coli	23	0.9	0.7	1.1	0.8
Campylobacter	20	2.0	0.6	2.1	0.7
Hand shaking					
APC	22	2.8	0.2	2.8	0.3
Coliforms	22	1.4	0.5	1.6	0.4
E. coli	22	1.0	0.5	1.1	0.5
Campylobacter	16	2.2	0.6	2.2	0.7

but there was lower variation in counts of bacteria from carcass rinse samples that were shaken by machine. The experimental design in the present study was chosen for sensitivity to left-right differences rather than for differences between the rinsing methods. Regardless of statistical analysis, differences between methods for the four types of bacteria that were enumerated were small (less than 0.2 logs). There is greater variation in *E. coli* counts relative to the magnitude of the mean, possibly due to the somewhat greater difficulty of counting *E. coli*. There is a high proportion of *E. coli* in coliform counts in poultry carcass rinses, and with both coliforms and *E. coli* counted on the same films, overlapping colonies, color differences, and gas bubbles may contribute to greater variability in *E. coli* counts. Due to the lack of differences between the two rinsing methods, data from both trials were combined for the rest of the analysis.

Left Half vs. Right Half

There were no significant differences in counts between left and right halves of carcasses for aerobic plate count, coliforms, and *Campylobacter* (Table 2). There was a significant difference in *E. coli* counts between the left and right halves, although the effect was small [difference between least-square means was 0.12 log (cfu/mL)] and of doubtful microbiological significance. When differences in *E. coli* counts between left and right halves were tested further by analyzing for differences within each sampling day using a random block design, there was

TABLE 2. Least-square means [log10 (cfu/mL)] and standard deviations for aerobic plate count (APC), coliforms, *Escherichia coli*, and *Campylobacter* in rinses of left and right carcass halves

Side	n	APC	Coliforms	*E. coli*	*Campylobacter* (n = 36)
Left	45	2.7 ± 0.4	1.5 ± 0.5	1.0* ± 0.6	2.1 ± 0.6
Right	45	2.7 ± 0.4	1.6 ± 0.5	1.1* ± 0.7	2.2 ± 0.7

*Least-square means for *E. coli* are significantly different (*P* = 0.04). Other means are not different (*P* < 0.05).

no significant left-right *E. coli* difference on any single day of sampling.

There is wide variation in left vs. right orientation of carcasses within processing plants due to design requirements of individual floor plans. Many poultry processing plants operate two kill lines that are mirror images of each other, with carcasses entering different stages of processing left side first on one line and right side first on the other. After killing, scalding, and defeathering, carcasses may change orientation when they are transferred to evisceration lines. Carcasses may also be rotated for specific pieces of equipment or for inspection. For carcasses that are removed from the processing line at the same point in a specific plant, however, it might be possible that a systematic lateral bias in bacterial counts could exist if plant equipment were somehow contaminating some part of the carcass consistently. All carcasses in this study were removed from the same processing line, on which all carcasses went through the plant right side first. The sole exception is that half of the carcasses passed through the inspection station left side first, but those carcasses were immediately switched back to right side first after inspection. Although the difference between left and right side counts in this experiment was either nonsignificant or quite small, it might be possible to find a long-term difference on a single line where the same side of carcasses was always presented first. The aiming of water sprays and the touching of pieces of equipment could possibly have a greater cleaning or contaminating effect on one side of carcasses.

The mean absolute value of differences in counts between the left and right halves were 0.2 ± 0.2 for APC, 0.2 ± 0.2 for coliforms, 0.3 ± 0.3 for *E. coli*, and 0.3 ± 0.2 for *Campylobacter*. Mean whole carcass counts [log10 (cfu/mL)] and standard deviations were 3.0 ± 0.4 for APC, 1.9 ± 0.5 for coliforms, 1.4 ± 0.6 for *E. coli*, and 2.5 ± 0.6 for *Campylobacter*. A histogram of *E. coli* counts on whole carcasses is shown in Figure 1, which does not indicate any obvious skewing in the distribution of counts before chilling. If some carcasses were being contaminated during processing, in addition to any bacteria on the carcasses on arrival at the processing plant, then the distribution of *E. coli* counts might have shown the added contamination by being skewed.

Correlations Between Carcass Halves

Correlations between counts on paired left and right halves of carcasses are shown in Table 3, with bacterial counts on carcass halves shown graphically in Figures 2 through 5. Lines with a slope of 1.0 have been included in the graphs for comparison. Correlations are high between the left and right halves of carcasses for all types of bacteria, so carcasses with high counts tend to have high counts on both halves. The four left halves with the highest *E. coli* counts and the four right halves with the highest *E. coli* counts were from the same four carcasses with the highest whole carcass *E. coli* counts. Coliforms
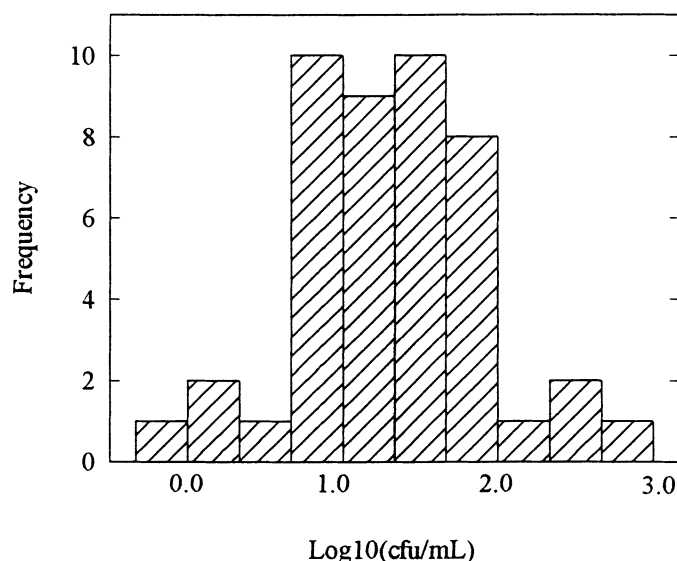

FIGURE 1. Histogram of whole-carcass *Escherichia coli* counts (sums of counts recovered from rinses of left and right halves of individual broiler carcasses removed from a processing line just before chilling).

are also consistent between halves on carcasses with higher numbers of whole carcass coliforms.

Whole Carcass: Absolute Left-Right Difference

Despite a lack of consistent left-right differences, it is still possible that specific instances of contamination might increase counts on one side of some carcasses. If high carcass counts indicate contamination during processing, then it seems unlikely that contamination would always occur exactly on the midline of the carcass. If specific events of contamination have a greater effect on bacterial counts on one half of the carcass than on the other, then left-right correlations should be reduced and greater left-right differences should be correlated with high carcass counts.

Correlations between whole carcass counts and absolute values of left-right count differences are shown in Table 3. Correlations were generally low between whole carcass counts and absolute difference between left and right sides of the carcass, with aerobic bacteria having the only significant correlation (r = 0.43). Figure 6 is a

TABLE 3. Correlation (r) and significance level (*P*) between left and right paired carcass halves and between whole carcass and absolute value of left-right differences for aerobic plate count (APC), coliforms, *Escherichia coli*, and *Campylobacter*

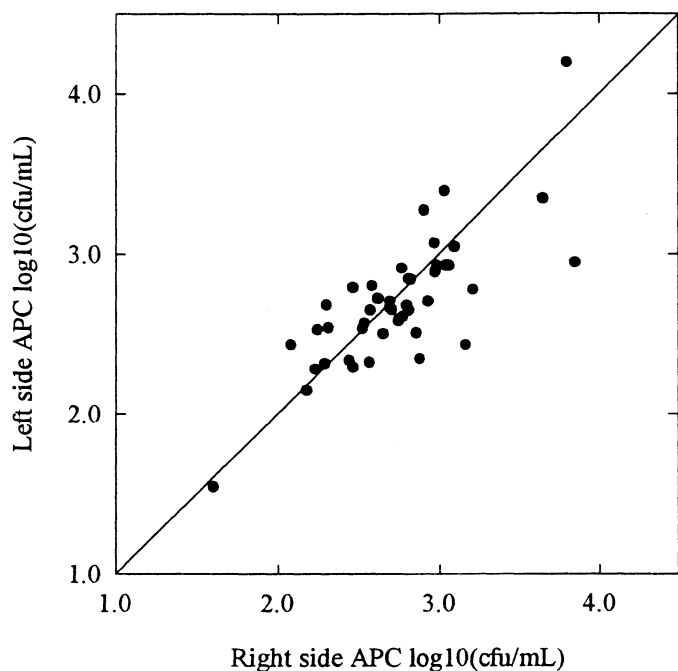|		Left:right		Whole:left-right difference	
	n	r	*P*	r	*P*
APC	45	0.78	0.0001	0.43	0.0028
Coliforms	45	0.83	0.0001	−0.03	0.86
E. coli	45	0.79	0.0001	0.15	0.32
Campylobacter	36	0.86	0.0001	0.03	0.87

FIGURE 2. Scatter plot of aerobic plate counts (APC) in rinses of paired halves of prechill broiler carcasses. Arbitrary reference line has a slope of 1.0.

FIGURE 4. Scatter plot of *Escherichia coli* counts in rinses of paired halves of prechill broiler carcasses. Arbitrary reference line has a slope of 1.0.

scatter plot of whole carcass *E. coli* counts against absolute left-right *E. coli* count differences. Whole carcasses with the highest counts do not tend to have the greatest differences between counts on half carcasses, so it appears that general bacterial contamination has a greater influence on carcass counts than do specific incidents of contamination in the processing plant. Large differences in counts
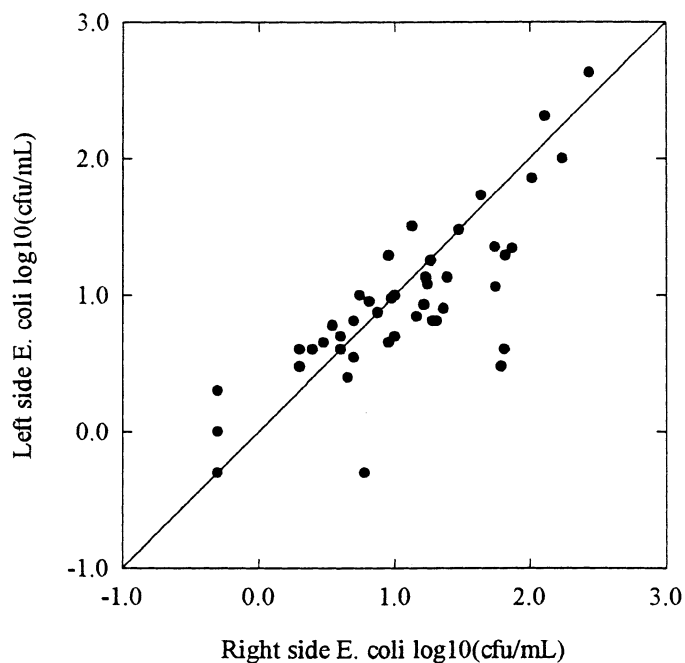
between half carcasses could be caused by problems in sampling or counting. In Figure 6 there are three carcasses with a log or greater difference between *E. coli* counts on the left and right halves (the right side was higher in all three instances), but in one case the right side count was below average for *E. coli*, and the corresponding left side was much lower than average. For all three carcasses,
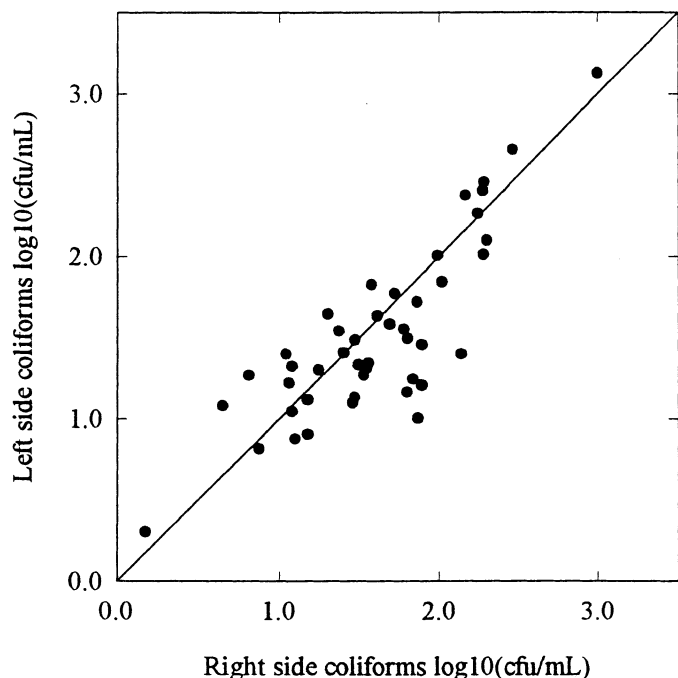

FIGURE 3. Scatter plot of coliform counts in rinses of paired halves of prechill broiler carcasses. Arbitrary reference line has a slope of 1.0.
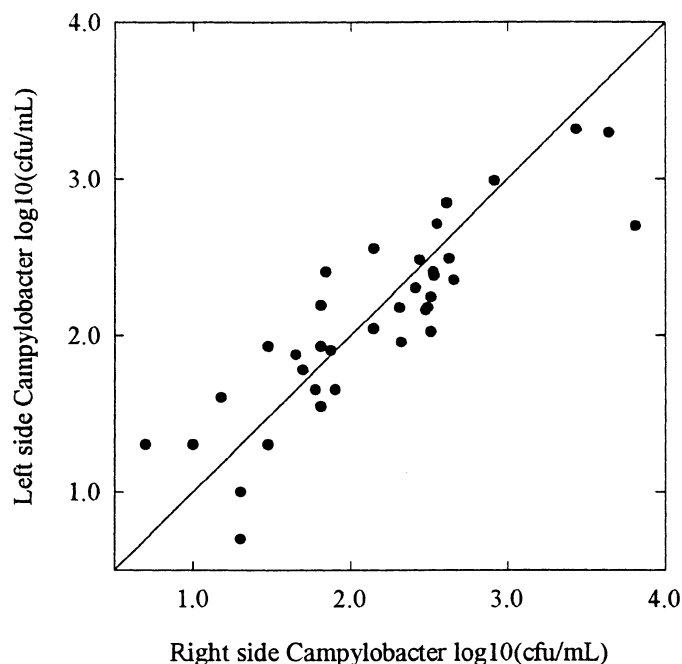

FIGURE 5. Scatter plot of *Campylobacter* counts in rinses of paired halves of prechill broiler carcasses. Arbitrary reference line has a slope of 1.0.
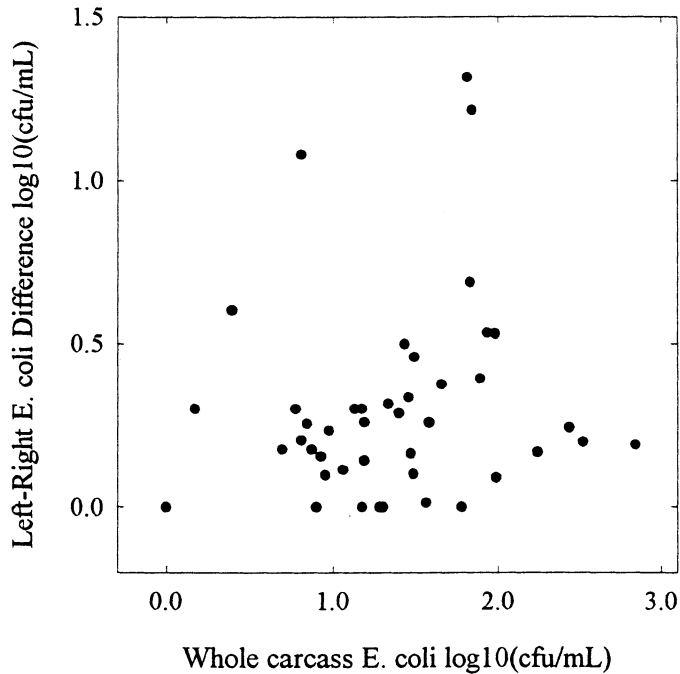
FIGURE 6. Scatter plot of whole carcass *Escherichia coli* counts and absolute left-right differences in *E. coli* counts on the same carcass determined from rinses of paired halves of prechill broiler carcasses.

differences in counts of other bacteria were either considerably smaller in magnitude or the left side had higher counts, so no problem with sampling was indicated.

Correlations between Different Bacteria

If fecal contamination in the processing plant makes a substantial contribution to carcass bacteria, or to the numbers of types of bacteria that are considered fecal markers, then statistical associations might be observed between different species of feces-borne bacteria recovered from processed carcasses. Notermans et al. (1977) tested the suitability of different types of bacteria as markers of fecal contamination during processing and found that fecal contamination could not be detected based on Enterobacteriaceae and *E. coli* counts in macerated skin samples except when samples came from a processing plant scalding broiler carcasses at 60 C, a temperature that is considerably higher than average. The numbers of fecal bacteria already present on the exterior of carcasses did not allow detection of fecal contamination during processing unless the beginning numbers on carcasses were reduced by high scalding temperatures. Notermans et al. (1977) was done with skin samples from the neck and pericloacal area, but if fecal contamination is asymmetric relative to left and right sides of carcasses, as it seems that it would be in most instances of specific fecal contamination, then examining counts on half carcasses might be a more sensitive test for evidence of fecal contamination compared to examining counts on whole carcasses.

Correlations between different kinds of bacteria on carcass halves are shown in Table 4. The correlation between

APC and *Campylobacter* on carcass halves was nonsignificant (0.19). On 36 *Campylobacter*-positive carcasses, the mean whole carcass APC concentration was 3.0 log10 (cfu/mL), compared to a mean APC of 3.1 on nine *Campylobacter*-negative carcasses. In previous work that sampled whole carcasses at various locations from before scalding to retail stores, there was no correlation between total counts and *Campylobacter* counts (Norberg, 1981; Kotula and Pandya, 1995; Cason et al., 1997; Buhr et al., 2000). There appears to be no meaningful predictive relationship between aerobic bacteria and *Campylobacter* in carcass rinses, even when *Campylobacter* is present and half carcasses are sampled to try to reduce variation.

The coliform-*E. coli* correlation on carcass halves in the present study was 0.69. A significant relationship between coliforms and *E. coli* was expected because *E. coli* is a subset of coliforms. Both types of counts have been considered evidence of fecal contamination when found in samples where fecal bacteria are not supposed to be found. When present in a flock, *Campylobacter* is also strongly associated with feces. It is sensitive to drying and atmospheric oxygen, so *Campylobacter* contamination might indicate more recent contamination than hardier bacteria such as coliforms or *E. coli*, which survive well under processing plant conditions. If fecal contamination occurs in the poultry processing plant and *Campylobacter* is present in the feces, then there might be a better correlation between *Campylobacter* and either coliforms or *E. coli* on half carcasses.

The coliform-*Campylobacter* and *E. coli*-*Campylobacter* correlations on carcass halves in the present experiment were 0.28 and 0.19, respectively. The coliform-*Campylobacter* correlation was significant at the 0.05 level, although that correlation accounts for less than 8% of the variation in *Campylobacter* numbers on half carcasses. The *E. coli*-*Campylobacter* correlation was not significant. Coliform-*Campylobacter* and *E. coli*-*Campylobacter* correlations in the same range or lower were reported by Buhr et al. (2000) in carcass rinses before scalding and after defeathering. The lack of a relationship between *E. coli* and *Campylobacter* counts can be seen in Figure 7, a scatter plot of counts on the same carcass in the present experiment. Previous studies have found poor predictive relationships between coliforms and *Campylobacter* (Norberg, 1981) and between *E. coli* and *Campylobacter* (Vorster et al., 1994). Coliform and *E. coli* counts in carcass rinses do not seem to have a useful predictive relationship with *Campylobacter*

TABLE 4. Correlations between aerobic bacteria, coliforms, *Escherichia coli*, and *Campylobacter* on half carcasses (n = 90 except n = 72 for correlations with *Campylobacter*)

	Campylobacter	Coliforms	*E. coli*
APC[1]	0.19	0.69***	0.39***
E. coli	0.19	0.69***	–
Coliforms	0.28*	–	–

[1]Aerobic plate count.
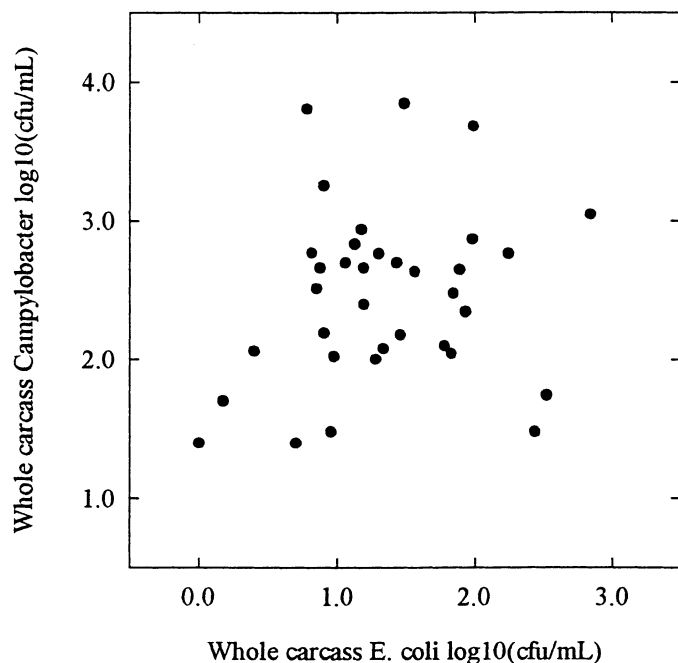*P < 0.05.
***P < 0.001.

FIGURE 7. Scatter plot of whole carcass *Escherichia coli* counts and whole carcass *Campylobacter* counts on the same carcass determined from rinses of paired halves of prechill broiler carcasses.

even when *Campylobacter* is present. Further discussion of relationships between index bacteria and pathogens on poultry can be found in Cason et al. (1997).

Effect of Reprocessing or Washing

Broilers transported and held on standard solid flooring had noticeably dirtier feathers and higher coliform and *E. coli* counts prior to scalding and picking compared to broilers on wire flooring, which prevented gross fecal contamination, but bacterial recovery from external carcass rinses did not differ between the solid and wire flooring treatments after feather removal (Buhr et al., 2000). These results indicate that initial carcass bacterial load upon entering the processing plant does not directly correlate with carcass bacterial load after feather removal. There may be no relationship or a weak one between fecal contamination on the feathers and on the skin, or the processes of scalding in hot water and mechanical defeathering might have altered the populations to the point that any relationship was ended.

Notermans and Kempelmacher (1975) suggested that keeping carcasses wet during processing prevented attachment of bacteria on the skin surface. Reprocessing studies have demonstrated that fecally contaminated carcasses can be cleaned to be equivalent to inspection-passed carcasses by washing soon after contamination occurs, either off line (Blankenship et al., 1975; Blankenship et al., 1993; Waldroup et al., 1993; Powell et al., 1995) or online (Fletcher et al., 1997). In four of five plants tested in the study of Waldroup et al. (1993) and in the study of Powell et al. (1995), reprocessed carcasses had significantly lower *E. coli* counts than did inspection-

passed carcasses. There is a higher volume of water used in plants today compared to previous years and more emphasis on carcass washers to avoid visible contamination. If there are correlations between some bacteria on fecally contaminated carcasses, those correlations might be affected as bacteria are removed from carcasses by vigorous washing.

Variations among Carcasses, Flocks, etc.

Renwick et al. (1993) found that carcass-to-carcass variation accounted for 73.2% of the variability in aerobic MPN estimates of prechill carcasses when between-farm (12.6%) and between-truck-within-farm (14.2%) variability were also included in the model. In the present study, with day-of-processing and carcass-within-day included in the model, carcass-within-day variability in counts of APC, coliforms, *E. coli*, and *Campylobacter* amounted to 72.9, 78.6, 67.6, and 62.2 % of the variation, respectively.

The suggestion of using paired halves of carcasses to test for treatment effects on salmonellae (Izat et al., 1990) appears to be valid for aerobic bacteria, coliforms, *E. coli*, and *Campylobacter*. Testing of chemical treatments will be more sensitive if paired carcass halves can be used to take advantage of reduced variability in numbers of bacteria compared to counts on different carcasses. High *E. coli* numbers on carcasses did not seem to indicate recent fecal contamination because the distribution of carcass *E. coli* counts was not skewed, *E. coli* numbers on individual carcasses were not correlated with left-right differences, and *E. coli* numbers were not correlated with *Campylobacter* numbers on half or whole carcasses when *Campylobacter* was present in feces.

ACKNOWLEDGMENTS

REFERENCES

Blankenship, L. C., J. S. Bailey, N. A. Cox, M. T. Musgrove, M. E. Berrang, R. L. Wilson, M. J. Rose, and S. K. Dua, 1993. Broiler carcass reprocessing, a further evaluation. J. Food Prot. 56:983–985.

Blankenship, L. C., N. A. Cox, S. E. Craven, A. J. Mercuri, and R. L. Wilson, 1975. Comparison of microbiological quality of inspection-passed and fecal contamination-condemned broiler carcasses. J. Food Sci. 40:1236–1238.

Buhr, R. J., J. A. Cason, J. A. Dickens, A. Hinton, Jr., and K. D. Ingram, 2000. Influence of flooring type during transport and holding on bacterial recovery from broiler carcass rinses before and after defeathering. Poultry Sci. 79:436–441.

Cason, J. A., J. S. Bailey, N. J. Stern, A. D. Whittemore, and N. A. Cox, 1997. Relationship between aerobic plate count, salmonellae, and *Campylobacter* on broiler carcasses. Poultry Sci. 76:1037–1041.

Dickens, J. A., N. A. Cox, J. S. Bailey, and J. E. Thomson, 1985. Automated microbiological sampling of broiler carcasses. Poultry Sci. 64:1116–1120.

Fletcher, D. L., E. W. Craig, and J. W. Arnold, 1997. An evaluation of on-line "reprocessing" on visual contamination and

microbiological quality of broilers. J. Appl. Poult. Res. 6:436–442.

Izat, A. L, R. E. Hierholzer, J. M. Kopek, M. H. Adams, M. Colberg, M. A. Reiber, and A. Mauromoustakos, 1990. The use of carcass halves for reducing the variability in salmonellae numbers with broiler-processing trials. Poultry Sci. 69:864–866.

Jacobs-Reitsma, W. F., A. W. van de Giessen, N. M. Bolder, and R. W. A. W. Mulder, 1995. Epidemiology of Campylobacter spp. at two Dutch broiler farms. Epidemiol. Infect. 114:413–421.

Jetton, J. P., S. F. Bilgili, D. E. Conner, J. S. Kotrola, and M. A. Reiber, 1992. Recovery of salmonellae from chilled broiler carcasses as affected by rinse media and enumeration method. J. Food Prot. 55:329–332.

Kinsley Jr., R. N., and G. J. Mountney, 1966. A comparison of methods used for the microbiological examination of poultry carcasses. Poultry Sci. 45:1211–1215.

Kotula, A. W., 1966. Variability in microbiological samplings of chickens by the swab method. Poultry Sci. 45:233–236.

Kotula, K. L., and Y. Pandya, 1995. Bacterial contamination of broiler chickens before scalding. J. Food Prot. 58:1326–1329.

McNab, W. B., S. A. Renwick, H. R. Lowman, and R. C. Clarke, 1993. Variability in broiler carcass bacterial load at three abattoirs, as measured by a hydrophobic grid membrane filter interpreter. J. Food Prot. 56:700–705.

Norberg, P., 1981. Enteropathogenic bacteria in frozen chicken. Appl. Environ. Microbiol. 42:32–34.

Notermans, S., and E. H. Kampelmacher, 1975. Attachment of bacteria to the skin of broiler chickens. Pages 21(1)–21(8) *in:* Proceedings of the Second European Symposium on Poultry Meat Quality, Oosterbeek, The Netherlands.

Notermans, S., F. M. van Leusden, and M. van Schothorst, 1977. Suitability of different bacterial groups for determining faecal contamination during post scalding stages in the processing of broiler chickens. J. Appl. Bacteriol. 43:383–389.

Notermans, S., R. J. Terbijhe, and M. van Schothorst, 1980. Removing faecal contamination of broilers by spray-cleaning during evisceration. Br. Poult. Sci. 21:115–121.

Powell, C., G. Blank, A. Hydamaka, and S. Dzogen, 1995. Microbiological comparison of inspection-passed and reprocessed broiler carcasses. J. Appl. Poultry Res. 4:23–31.

Renwick, S. A., W. B. McNab, H. R. Lowman, and R. C. Clarke, 1993. Variability and determinants of carcass bacterial load at a poultry abattoir. J. Food Prot. 56:694–699.

Rigby, C. E., 1982. Most probable number cultures for assessing Salmonella contamination of eviscerated broiler carcasses. Can. J. Comp. Med. 46:279–282.

SAS Institute, 1987. SAS/STAT® Guide for Personal Computers. Version 6 Edition. SAS Institute Inc., Cary, NC.

Stern, N. J., B. Wojton, and K. Kwiatek, 1992. A differential selective medium and dry ice generated atmosphere for recovery of *Campylobacter jejuni*. J. Food Prot. 46:339–344.

Thomas, C. J., and T. A. McMeekin, 1980. A note on scanning electron microscopic assessment of stomacher action on chicken skin. J. Appl. Bacteriol. 49:339–344.

Vorster, S. M., R. P. Greebe, and G. L. Nortje, 1994. Incidence of *Staphylococcus aureus* and *Escherichia coli* in ground beef, broilers and processed meats in Pretoria, South Africa. J. Food Prot. 57:305–310.

Waldroup, A. L., B. M. Rathgeber, R. E. Hierholzer, L. Smoot, L. M. Martin, S. F. Bilgili, D. L. Fletcher, T. C. Chen, and C. J. Wabeck, 1993. Effects of reprocessing on microbiological quality of commercial prechill broiler carcasses. J. Appl. Poult. Res. 2:111–116.